# **Earthquakes**

## **Chapter 3**

# **Learning Objectives**

## Understand how scientists measure and compare earthquakes

## The processes behind earthquakes, i.e. faulting, tectonic creep, and the formation of seismic waves

## Which global regions are most at risk for earthquakes and why

## Understands the effects of earthquakes, such as shaking

## Learn the other hazards linked with earthquakes

## Understand the important natural service of earthquakes

## Understand how human beings interact with and affect the earthquake hazard

## Understand how we can minimize seismic risk and what can be done to protect ourselves

# **Earthquake from Disasters to Catastrophes**

## Earthquakes are devastating events

### These earthquakes can be **catastrophic** when the population is huge or when structures are not built to withstand an earthquake

## Earthquakes may **develop from the movement of magma or sudden ground subsidence**.

## **Fault movement allows an abrupt release of energy, usually after a long, slow accumulation of strain**

## **Fault rupture can take place at the surface and displacement can take place at considerable depth**

# **Earthquakes**

## A **vibration in the Earth produced by shock waves resulting from a sudden displacement along a fault**

## Earthquakes may also **develop from the movement of magma or sudden ground subsidence**

## **Fault movement allows an abrupt release of energy, usually after a long, slow accumulation of strain**

## **Fault rupture can take place at the surface and displacement can take place at considerable depth**

# **Introduction to Earthquakes**

## **Earthquakes are compared by the amount of energy released**

## **Magnitude** – the relative amount of energy released during an earthquake

## **Shaking Intensity**– intensity scale devised by Giuseppe Mercalli in 1902

### Updated to the **Modified Mercalli intensity scale**

## **The area where the earthquake starts is called the Epicenter**

### This is where the ruptured rocks broke to produce the earthquake

# **Earthquake Magnitude and Intensity**

## **Magnitude** - is **determined from an estimate of the area which ruptured along a fault plane during the quake**

## It is calculated on a logarithmic scale

## Each difference in scale is 32 times more intense than the previous

### 32 times more energy is released

### Magnitude scale was developed by Charles Richter

## Recently “**Moment Magnitude** ” has been developed to be used by seismologists

## Used to describe very large earthquakes or – **the Earthquake Intensity**

## **Moment Magnitude** estimates the area of rupture along the fault plane during a quake, the amount of movement or slippage along the fault, and the rigidity of the rocks near the focus of the quake

## **Used to prepare online *Community Internet Intensity Maps***

## To help identify where the greatest shaking could take place, ***shake maps***are developed to help identify where the greatest shaking could take place

# **Earthquake Processes**

## **Process of Faulting**

### A **fracture or fracture system** where rocks have been **displaced**

### Long-term rate of movement is known as the ***slip rate***

### When the **rupture begins**, it starts at the **focus** and then **propagates up, down, and laterally along the fault plane** during the earthquake

### The sudden rupture of the rocks produces ***seismic waves***

### Basically the earthquake **releases pent-up energy** of the strained rocks as **waves of energy**

# **Faults**

* **Types of faults**
* **Strike Slip – Transform** -a block of crust moves mainly in a horizontal direction
* **Dip-Slip** – A block of the crust moves mainly in a vertical direction
  + **Over-thrust Fault** – Hanging wall moves over the foot wall at an angle
  + **Normal or Reverse Fault** – Hanging wall moves up or down relative to the foot wall
* **Blind Fault –** The fault does not extend to the surface of the earth

## **Fault Activity**

### **Active**- if movement during the last 200 – 10,000 years

### **Potentially Active**- if movement during the 10,000 – 1,650,000 Years

### **Inactiv**e – if movement during 65,000,000 to 4.6 billion years ago – the age of the earth

## **Faulting results when rock is broken under stress and displacement happens**

### **Fault zones --** an area of weakness in the crust

### **Fault line** – the intersection a fault zone with the Earth’s surface

### **Fault scarps** – steep cliffs that represent the edge of a vertically displaced block

# **Tectonic Creep and Slow Earthquakes**

## **Tectonic Creep** – the gradual movement along a fault which can’t be felt

### These are called **slow earthquakes or fault creep**

### Slowly causes damage to anything built over the land

#### Example: Suncrest housing development built on old slide or creep

#### Roads are cracking and sliding down the mountain

## **Newly recognized using GPS devices used to capture geodetic movement**

# **Seismic Waves**

## **Start at the Focus – or the epicenter of the earthquake.** (Waves move out from the epicenter like waves in water when rock thrown in)

### **P Waves** – **Compressional waves** which move through the Earth like sound waves alternately compressing and relaxing the medium that they pass through (**like a slinky**). Moves through **both solids and liquids and gases**

### **P Waves** move **more quickly through solids** than through liquids

### When **P Waves** reach the surface of the earth they can be heard by animals and birds

#### This is not the sounds that people hear just before an earthquake, which is sound of objects shaking

## **S Waves**– **Shear or secondary waves which move strong side-to-side, up and down slowing moving waves**

### The **up and down movement (sideways shear**) produced a whipping back and forth moment

### T**his sideway shearing motion which does not allow for the wave to spring back in liquids**

### **S Waves** can **only move through solids**

### **Both P waves and S waves** are “**body waves**” because they **develop in the body of the earth**

## **Surface waves** immediately after the P and S waves arrive on the surface and producing a **strong side-to-side movement as well as the up-and-down “rolling” motion**

### One type of **surface wave** is called a ***Love Wave*** which especially damages foundations

# **Earthquake Shaking**

## **Three important factors** determine the shaking you will experience during an earthquake

### **Earthquake magnitude**

### **Your location in relation to the epicenter and direction of rupture**

### **Local Soil and rock conditions**

## **Generally strong shaking may be expected from earthquakes of moderate magnitude (M 5 – 5.9) or larger**

## **These types of earthquakes will cause the ground to rock and roll damaging building and other structures**

## **Distance from the Epicenter**

### Using **Seismographs** which produce a seismogram, the epicenter can be located by looking at the travel speed of the P and S waves

### Scientists use triangulation from more than 4 seismic centers to locate the Epicenter

## **Depth of Focus**

### The **depth of the earthquake focus** determines how much “**shaking**” will happen

### The deeper the focus the less shaking is felt on the surface

### Seismic waves lose much of their energy (***attenuation***) if the focus is deep in the earth

## **Direction of Rupture**

### Although the rupture from the focus may move in many directions **the path of the greatest rupture can focus the earthquake energy**. This is the **directivity**.

#### **Contributes to the *amplification of seismic waves and shaking***

* **Supershear**
* Occurs when the **propagation of rupture** is **faster** than the **velocity of shear-waves or surface waves** produced by the rupture
* Supershear can produce **shock waves that produce strong ground motion** along the fault
* The **nature of the local earth materials and geologic structure strongly influences the amount of ground motion**
* Earth materials **behave differently in an earthquake**
* If the earth material causes the **P and S waves to slow down** the forward **energy is focused vertically**; this is known as **material amplification**
* This movement strongly **influences the ground motion** of an earthquake
* **Local geologic structures** can also influence the amount of shaking
* **Synclines and fault-bounded sedimentary basins can focus seismic waves the way a magnifying lens focuses sunlight**
* This causes **severe shaking in some areas and less intense shaking in others**

# **The Earthquake Cycle**

## From the 1906 San Francisco earthquake observations were made that led to a hypothesis known as the **earthquake cycle**

## The **earthquake cycle proposes that there is a drop in elastic strain after an earthquake and a re-accumulation of strain before the next event**

### **A long of inactivity along a segment of a geologic fault**

### **Accumulated elastic strain produce small earthquakes**

### **Consists of foreshocks happen hours or days before the main earthquake In some cases this event may not happen**

### **The main event is the *mainshock*, the major earthquake and its *aftershocks and the mainshock epicenter***

# **Geographic Regions at Risk from Earthquakes**

## ***Earthquakes are not randomly distributed***

## There are **well-defined zones along the boundaries of Earth’s tectonic plates**

## **Plate Boundary Earthquakes**

### Earthquakes occur along all three types of plate boundaries

#### **Convergent**

#### **Divergent**

#### **Transform**

### The world’s greatest earthquakes which have happen in the last 100 years have been along **megathrust subduction zones**

#### These are called **megathrust earthquakes**

## Places like **Los Angeles, San Francisco**, and other places along **transform plate boundaries** often have earthquakes

## The states along the **Rocky Mountains (including Utah) experience many earthquakes**

## **Knowing the probably location, the magnitude and effects of an earthquake allows for plans to be made to decrease loss of life and damage**

## **Intraplate Earthquakes**

### **Less common**

### **Can be large and extremely damaging**

### They **don’t happen often** so **people are less prepared for them**

#### There were **two large earthquakes 1811-12** during the winter in the central Mississippi Valley

#### These were felt all over the eastern states from New Orleans to Boston to Quebec City

#### Produced a intense surface deformation over a wide area of Memphis, Tennessee north to the confluence of the Mississippi and Ohio Rivers

#### These two earthquakes occurred along the New Madrid seismic zone, part of a geologic structure known as the Mississippi Embayment

#### It is figured that earthquakes happen along this embayment at a *recurrence interval*, once every several hundred years

**Effects of Earthquakes and Linkages with other Natural Hazards**

## **Shaking is not the only cause of death and damages during earthquakes**

### **Earthquakes often cause linkages to other natural hazards**

## **Shaking and Ground Rupture**

### A major ground rupture from an earthquake causing a short cliff is called a **Fault Scarp**

#### This cliff is not an “opening to the inside of the earth” like some movies insinuate

### **Buildings can experience damage by violent shaking called ground acceleration**

#### This ground acceleration shaking causes the building to shake by matching its frequency or **resonance**

## **Liquefaction**

### **Shaking of water-saturated material** Turns **clay soil to fluid resulting in subsidence, fracturing, and horizontal sliding** of the ground surface

## **Regional Changes in Land Elevation**

### **Vertical deformation of the land surface** is linked to large earthquakes

### Includes regional uplift and subsidence of the earth’s surface

### Can cause substantial damage to coastal areas and along streams

## **Landslides**

### **Landslides are the closest physical link to earthquakes**

### Earthquakes are the most common trigger of landslides

### Can be extremely damaging and cause a large loss of life

## **Fires**

### **Happens when surface is displaced and electrical power and natural gas pipes break**

### Larger threat when water mains break, roads and bridges broken, blocking fire equipment ability to get to fire and put it out

## **Disease**

### **Outbreaks of diseases** sometime occur during large earthquakes because of the **loss of sanitation, housing, contamination of water** and other public health problems

# **Natural Service Functions of Earthquakes**

## Finding **benefits** from earthquakes can sound like it would be difficult, but there are some **natural service functions** from earthquakes

## **Groundwater and Energy Resources**

### Movements of faults as a result of earthquakes allow the **underground flow of water, oil, and natural gas**

## **Mineral Resources**

### Faulting from earthquakes may be responsible for the **accumulation or exposure of economically valuable minerals**, like **veins of gold, silver or other valuable minerals**

#### **Oquirrh Mountains (many types of minerals)**

## **Landform Development**

### **Earthquakes** can form **scenic landforms** over long intervals of geologic time

#### **Some parts of central and southern Utah**

## Future Earthquake Hazard Reduction

### By having **small earthquakes the tension is released** avoiding that “big one”

### 

# **Human Interaction with Earthquakes**

## **Earthquakes Caused by Human Activity**

### **Four ways the actions of people** have caused earthquakes

#### **Over -Loading the Earth’s crust with building a dam and reservoir**

#### **Injecting Liquid waste deep water into the ground through disposal wells**

#### **Creating underground nuclear explosions**

#### **Hydraulic Fracturing-exploring for oil and natural gas**

## **Loading the Earth’s crust as in building a dam and reservoir**

### **Water reservoirs may create or induce earthquakes**

#### The huge weight of the water can create or extend fractures in adjacent rock

#### Increases water pressure in the surrounding groundwater causing earthquakes

## **Injecting liquid waste deep into the ground through disposal wells**

### **Deep Waste Disposal** was an experiment of the US Army in the 1960’s

### **This experiment** provided the direct evidence that injecting fluids into the earth can cause earthquakes

### Increases underground fluid and pressure **which caused slippage of numerous fractures of metamorphic rock**

### **When this was discontinued, the earthquakes quit, an important find**

## **Creating underground nuclear explosions**

### During the **1960’s (again) the testing of nuclear explosions was moved from the surface to underground protecting people living downwind**

### It was thought that these **explosions could be used to release the seismic tension in underground rock**

### It **really doesn’t work**, and there is still the problem of having any nuclear explosions

## **Hydraulic Fracturing (Fracking)**

### The **new way of looking for oil, coal, shale gas, or natural gas**

### Found in Oklahoma, Pennsylvania, Ohio, and many other states

### Started in 1947, lately being used more in the past 10 years

### Besides the **environmental problems that can occur, earthquakes have been tied to fracturing**

### In 2011, **Oklahoma experienced its largest earthquake**. It was thought to be linked to fracturing processes being practiced in the state, but the **USGS declared it was probably natural**

### **Other earthquakes have been felt in areas where fracturing has been used**

# **Minimizing the Earthquake Hazard**

## **Earthquakes cause lots of damage and loss of life consequently there has been research into how to forecast an earthquake**

## It would be hoped that by forecasting earthquakes lives and damage can be decreased

## So the **National Earthquake Hazard Reduction Program was formed with these goals**

### **Develop and understanding of the earthquake source**

#### Requires obtaining information about the physical properties and mechanical faults and develop models about the process

### **Determine earthquake potential**

#### Study the seismically active regions to determine their paleo-seismicity, identify active faults and rates of deformation

### **Predict effects of earthquakes**

#### Obtain information needed to calculate the predict the ground rupture and shaking on buildings

### **Apply research results**

#### The program educates individuals, communalities, states, and the nation about earthquakes

## **Estimation of Seismic Risk**

### Seismic hazard maps can be used to help formulate where earthquakes can happen

## **Short-term Prediction**

### Active area of research

### Relies on precursors, events or changes that occur prior to main shock

### Doesn’t always work, prediction a complex problem

### If predictions actually are formulated they will be based on

#### Patterns and frequency of

#### Deformation of the ground surface

#### Seismic gaps along faults

#### Geophysical and geochemical changes

## **The Future of Earthquake Prediction**

### Scientists have been **working on prediction but still haven’t got a good system**

### **Progress has been made on short-term, but long-term forecasting is still a long way off**

## **Earthquake Warning Systems**

### It is technically feasible that an earthquake warning system could be made that would give a 1 minute warning

### But **if** there were false alarms, people would begin to not take them seriously

# **Perceptions and Adjustments to the Earthquake Hazards**

## **Perception of the Earthquake Hazard**

### Because **there aren’t ways to predict or warn people of earthquakes there are problems with the perception of and adjustment to the earthquake**

### Society **is vulnerable to catastrophic loss from large earthquakes due to old buildings, too big of buildings , and many other problems**

## **Community Adjustments to the Earthquake Hazard**

### Since we can’t avoid living in earthquake prone areas, society needs to take steps to adjust to the earthquake hazard by doing these following steps to avoid these hazards

### **Location of Critical Facilities**

#### Facilities which are critical to communities need to located in safe areas

### **Structural Protection**

#### The need to build buildings so they don’t fall down and kill people will make society safer if an earthquake should happen

### **Education**

#### Education on what and how to protect yourself during an earthquake and how to build earthquake safe, decreases the hazards of earthquakes

### **Increase Insurance and Relief Measures**

#### If you are in an earthquake prone area, take get earthquake insurance,

## **Personal Adjustments**

### Make adjustments to your home to make it earthquake safe and have a plan if an earthquake happens